音頻系統的聲音品質
Sound Quality of Audio Systems

2024

Klippel GmbH

自我介紹 To introduce ourselves:

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Previous Lectures

讓我更了解你的背景
To introduce you

你的背景和你感興趣的領域是什麼？

What is your background and your field of interest?

(Multiple responses are possible)

A. 聲學和音頻工程Studying acoustics and audio engineering
B. 傳感器開發 Transducer Development
C. 音頻系統 Audio System Integration
D. DSP軟體 DSP Software
E. 測量和模擬 Measurement and Simulation
F. 市場營銷管理 Marketing, Management
G. 製造 Manufacturing, Support
H. 研究 Audio Research
I. 其他 Others

課程內容 Roadmap

Two day courses

第一天 First Day

1. 介紹 – 基本術語和內容的定義 Introduction – definition of basic terms & roadmap
2. 集總參數 - 線性建模和測量 Lumped parameters - linear modeling & measurement
3. 分佈式機械參數—錐體振動分析 Distributed mechanical parameters – cone vibration analysis
4. 聲輻射和房間相互作用—預測和測量 Sound radiation and room interaction – prediction and measurement
5. 非線性建模 – 概述 Nonlinear modeling – overview
6. 非線性參數的測量 - 解釋 Measurement of nonlinear parameters – interpretation

第二天 Second Day

1. 常規非線性失真 - 診斷 Regular nonlinear distortion – diagnostics
2. 時變特性 - 加熱、老化 Time-varying properties - heating, aging
3. 異音（ “摩擦和嗡嗡聲” ） - 不規則振動，缺陷 Abnormal sound (“rub&buzz”) - irregular vibration, defects
4. 可聽性和對音頻質量的影響 - 可聽性 Audibility and impact on audio quality - auralization
5. 揚聲器的自主感測及非線性控制 Adaptive Nonlinear Control of speakers

簡報及講義標示 Some Tips

什麼重要什麼不重要？What is important what is not ?
注意以下的標示 Note the following icons:

R 指示回顧過去的教材（我們保持簡短）Review of familiar material (we keep it short)

! 指示新的而且重要的資訊 New and most important information

指示高級或特殊題目（可選擇的素材 ）
Advanced or special subject (optional material)

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Part 1:小信號模型

Part 1: Small Signal Modeling

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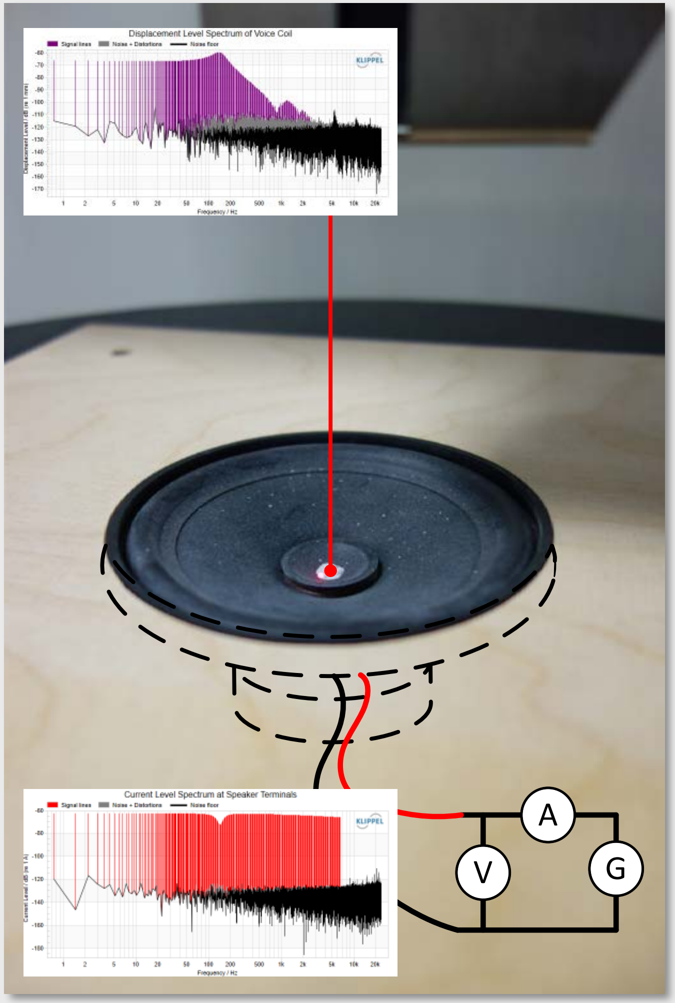
線性參數測量 (FLSI)
Linear Parameter Measurement (FLSI)
Experiment 1



- 最佳設定（雷射、電流感測器、模板）

Optimal Setup (Laser, current sensor, Template)

- 關鍵測試條件（激發、定位、環境）

Critical test condition (Stimulus, positioning, environment)

- 確保準確性（參考揚聲器，增加品質/雷射方法之間的重合）

Ensuring Accuracy (reference speaker, coincidence between added mass/laser method)

- 快速、可靠的測試（平均、SNR）

Fast, reliable testing (averaging, SNR)

- 解釋（非線性、蠕變、有損電感、SD、漏氣）

Interpretation (nonlinearities, creep, lossy inductance, SD, leaky box)

- 結果解釋

Interpretation of the results

- 警告訊息

Warning Messages

線性揚聲器模擬 (LSIM)
Linear Loudspeaker Simulation (LSIM)
Experiment 2

- 使用寬頻類音訊刺激（頻譜和波峰因數）進行建模

Modelling with broadband, audio-like stimulus (spectrum and crestfactor)

- 考慮帶負載的感測器（音箱、被動輻射器、面板）

Considering transducer with load (box, passive radiator, panel)

- 自動均衡（DSP）

Automatic equalization (DSP)

- 目標效能（SPL(f,r)、最大 SPL）

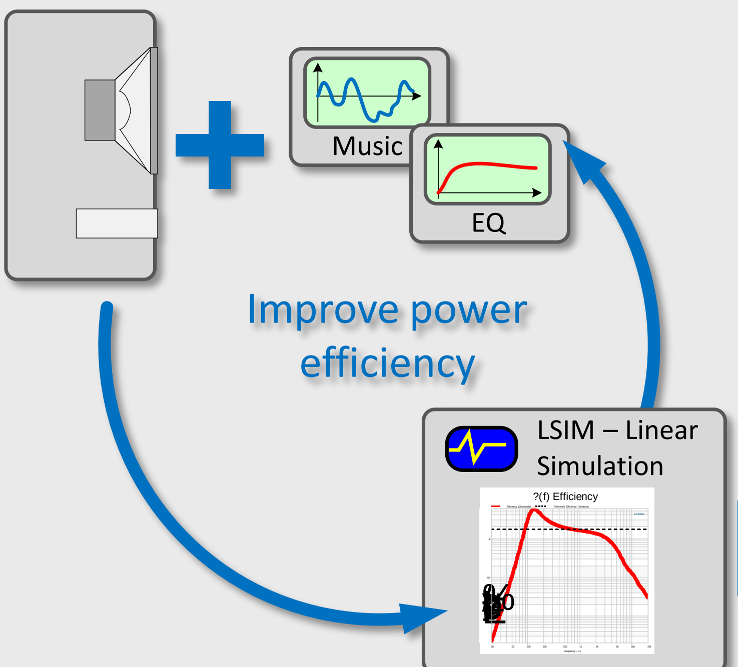
Target Performance (SPL(f,r), max SPL)

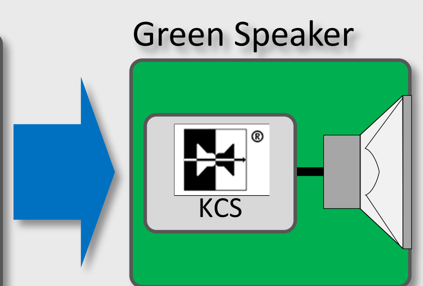
- 臨界值（Xpeak、Upeak、Pe、max）

Critical limits (X_{peak},U_{peak},$P_{e,max}$)

- 效率對於綠色揚聲器設計很重要

Efficiency important for Green speaker design





線性集中參數
Linear Lumped Parameters

- 線性集中參數模型是揚聲器和系統設計的基礎
  Linear model with lumped parameters is the basis for transducer and system design
- 進一步模擬電感與潛變對於參數的確認是必要的
  Advanced modeling of inductance and creep are required for accurate identification of the parameters
- 勁度、共振頻率和相關參數取決於最大位移量、溫度、濕度以及老化程度
  Stiffness, resonance frequency and related parameters depend on peak displacement, temperature, humidity, aging
- 在真空中測量時，空氣負載造成的質量可以不考慮
  Mechanical elements (M_{ms}) can be separated from acoustical elements (moving air mass M_{air}) by performing measurements in vacuum

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Part 2:

Part 2: Modal Vibration at High Frequencies

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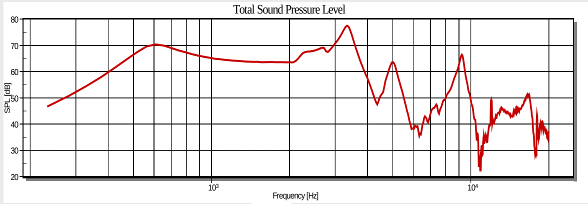
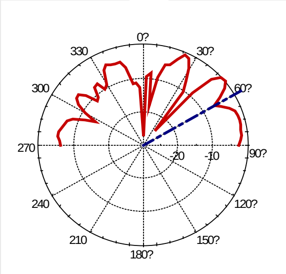
今天的主題
Our Topic Today

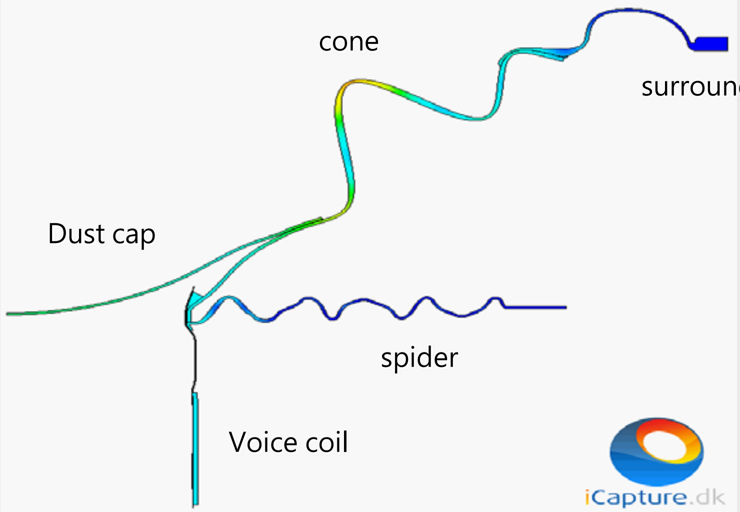
PERFORMANCE





Relationship ?

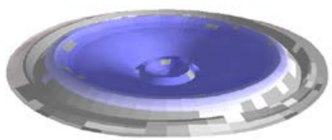
設計幾何形狀和材料
DESIGN (geometry, material)



Simulation by Ulrik Skov

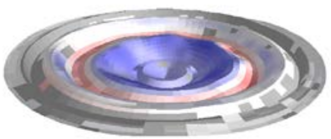
- **那些參數限制了可用頻率的範圍?**
  What limits the usable frequency range ?
- **是什麼導致了分割振動後在曲線上出現的峰和谷變化**
  What causes peaks and dips in the SPL response after break-up ?
- **怎樣測量機械振動**
  How to measure the mechanical vibration ?
- **哪些機械模態有用，哪些沒用?**
  Which mechanical modes are beneficial which are not ?
- **怎樣處理振動和輻射問題?**
  How to cope with vibration and radiation problems ?
- **怎樣得到光滑的回應曲線、最佳指向性以及較低的失真**
  How to get smooth responses, optimal directivity and low distortion ?

錐體振動分析 (SCN)
Cone Vibration Analysis (SCN)
Experiment 3



150 Hz

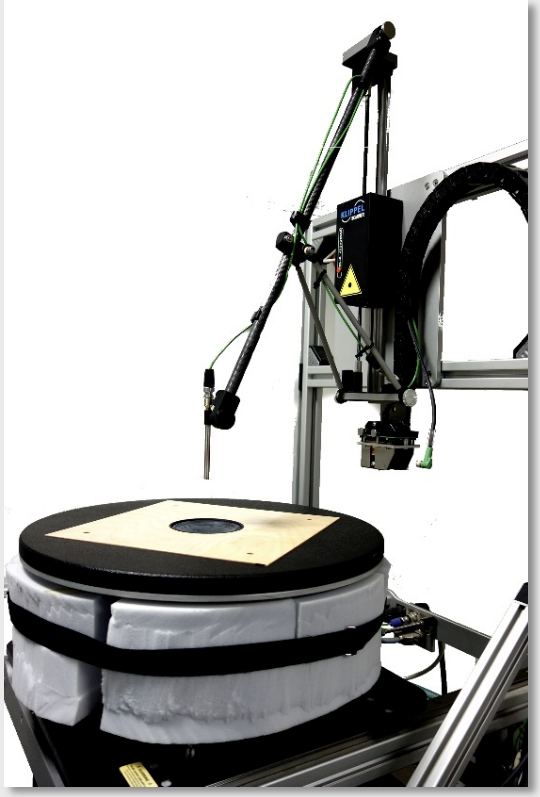
1 kHz



5 kHz

Topics:

- 實踐機械掃描
Mechanical Scanning in Practice
- 最短掃描時間
Minimum scanning time
- 錐體振動的可視化
Visualization of cone vibration
- 輻射估算
Radiation estimation
- 聲功率
Sound power



分布機械參數
Distributed Mechanical Parameters
Summary

- **在機械與聲學邊界上描述振動子的振動與幾何**
  Describe the geometry and vibration of the radiator at the boundary between mechanical and acoustical domain
- **能夠被整合到AAL**
  Can be integrated to an accumulated acceleration level (AAL) which is the basis for modal analysis
- **顯示自然頻率、阻尼與模態的形狀**
  Show the natural frequencies, damping and the shape of the modes
- **支援周向與勁向模態的識別**
  Support the identification of circumferential and radial modes

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Part 3:

Part 3: Sound Radiation and Room Influence

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聲學近場掃描（SCN、NFS）
Acoustical Near-field-Scanning (SCN, NFS)
Experiment 4

- 聲學掃描的實踐

Acoustical scanning in practice
- 最短掃描時間（對稱）

Minimum scanning time (symmetry)
- 全像場識別

Holographic field identification
- 評估解析度和準確性

Evaluating resolution and accuracy
- 從近場推斷到遠場

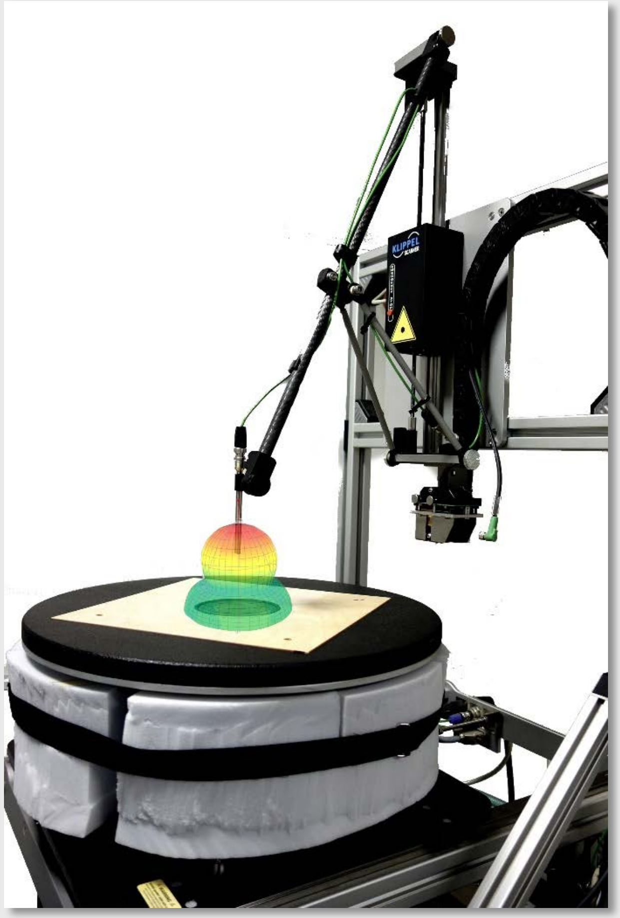
Extrapolating from Near-field to Far-field
- 指向性和聲功率的解讀

Interpretation of Directivity and Sound Power
- 無消音室測量

Measurement without anechoic room
- 帶有無限擋板的半空間測量

Half-space measurement with infinite baffle
- 應對擋板振動

Coping with baffle vibrations



原位房間補償 (ISC)
In-Situ Room Compensation (ISC)
Experiment 5

Topics:

- 目標：在工作台上快速測試相同或相似感測器類型的單元（無需掃描）

Target: Fast testing of units of the same or similar transducer type (without scanning) in the working bench

- 來自 NFS 的準確自由場參考資料

Accurate Free-field Reference Data from NFS

- 產生模擬異地標準條件（根據 IEC 60268-21/23）

Generating simulated Ex-Situ standard conditions (according to IEC 60268-21/23)

- SPL 頻率響應和 THD 的測量

Measurement of the SPL frequency response and THD

聲場特性（NFS 視覺化）
Sound Field Characteristics (NFS Visualization)

Experiment 6

- 遠場特性（氣球圖）

Far-Field Characteristics (Balloon)

- 軸上響應 (1m)

On-Axis Response (1m)

- 聲功率響應

Sound Power Response

- 方向性

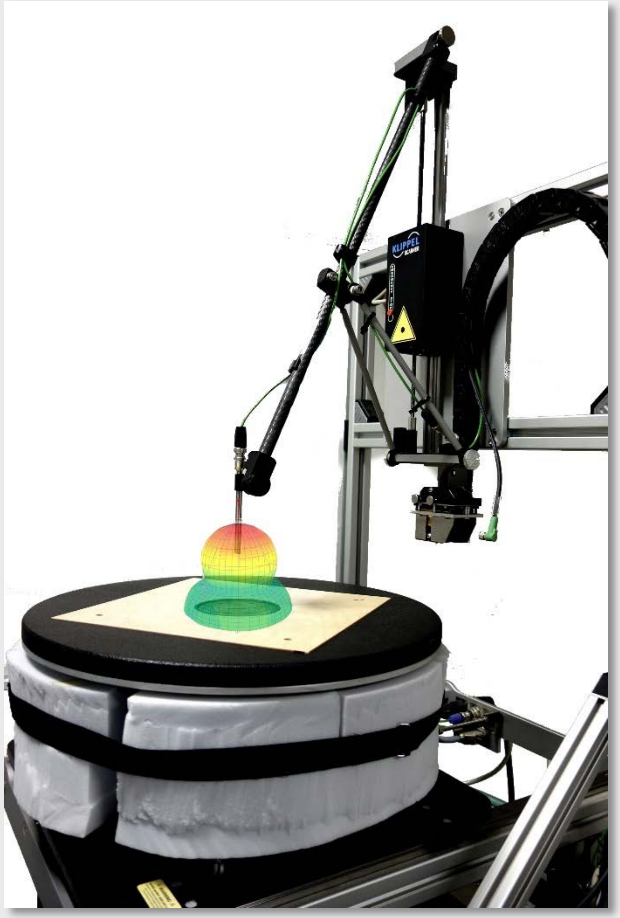
Directivity

- 監聽視窗（CTA 和 IEC）

Listening Window (CTA and IEC)

- 聲學區 (IEC)

Acoustical Zone (IEC)



小信號區域診斷-重要參數和分析
Diagnostics in the Small Signal Domain
Important Parameters and Analyses

1.換能器Transducer
-集中參數 Lumped Parameters (Thiele-Small)
-分佈機械參數Distributed mechanical parameters
-累積加速度級,模態分析 Accumulated accleration level, modal analysis

2.消聲室中的揚聲器 Loudspeaker in Anechoic Room (Ex-Situ)
-軸向與非軸向的遠場聲壓級回應SPL Far-field resonse on-axis and off-axis (polar data)
-指向性指數，聲功率回應Directivity index, sound power response
-聲壓相關分析Sound pressure-related decomposition
-球面諧波的係數Coefficients of Spherical Harmonics

3.揚聲器與房間的相互作用 Loudspeaker-Room Interaction (In-Situ)
-在聆聽點的穩態回應Steady-State response at listening points (spatial average)
-時頻分析(累積的頻譜衰減) Frequency-Time Analysis (cummulative decay spectrum)
-分解成直達聲,反射聲,混響聲 Decomposition into direct sound, reflections, reverberant sound

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Part 4: Loudspeaker Nonlinearities

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本節概要

Topics addressed in this section

- 概述揚聲器裡的主要非線性特性
  Overview on Dominant Nonlinearities in Loudspeaker
- 聲輸出的限制
  Limitation of the Acoustical Output
- 非線性失真的產生對聲音品質有所影響
  Generation of Nonlinear Distortion, Impact on Sound Quality
- 小型揚聲器最佳性能之設計
  Design of Small Speakers with Optimal Performance
- 微型揚聲器特色
  Particularities of Microspeakers

總結 Summary

- **非線性與熱的機制將會限制揚聲器最大的訊號表現**
  Nonlinear and thermal mechanisms limit the large signal performance of loudspeakers
- **控制揚聲器非線性主要來自電動換能器以及內部的懸吊系統**
  The dominant nonlinearities of loudspeakers are located in the electro-dynamical transducer and in the suspension system
- **集中參數系統是有用的**
  A lumped parameter model is useful
- **非線性特性可利用來自多個自變數變化的參數表示**
  Nonlinearities can be represented by parameters which are not constant but vary with one or more state variables.

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Part 5: 揚聲器非線性參數的量測
Part 5: Measurement of Nonlinear Loudspeaker Parameters

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本節概要

Questions addressed in this section

- 如何完成有意義的大信號測試?
  How to perform meaningful measurements in the large signal domain ?
- 如何詮釋說明設計的結果及改善設計?
  How tointerpret the results and to improve the design ?
- 如何取得系統設計完整的所需資料?
  How to get a comprehensive set of data required for system design ?
- 如何選取系統適用的單體喇叭?
  How to select an optimal driver for loudspeaker system design ?
- 如何調整音圈尺寸配合磁間隙？
  How to find the optimal size of voice coil in the gap ?
- 揚聲器的非線性特質,何者是好的及何者是不好的？
  Which loudspeaker nonlinearities are good and which are bad ?
- 如何得到最大的承受功率及電聲輸出?
  How to get maximal power handling and acoustical output ?
- 如何在小的音箱得到最佳的低頻效果？
  How to get maximal bass out of a small enclosure ?
- 如何得到有意義的失真測量？
  How to do meaningful distortion measurements ?
- 如何量測承受功率？
  How to measure the power handling ?

快速非線性參數測量 (FLSI)
Nonlinear Parameter Measurement (FLSI)
Experiment 7

- 使用多音激發的自適應非線性控制 (KCS) 的快速初始參數識別

Fast Initial Parameter Identification for Adaptive Nonlinear Control (KCS) using multi-tone stimulus

- 尋找工作範圍的極限（Xmax、Umax、Pmax），同時避免過載和過度失真

Finding limits of working range (X_{max}, U_{max}, P_{max}) while avoiding overload and excessing distortion

- 考慮高階負載（例如開孔音箱）

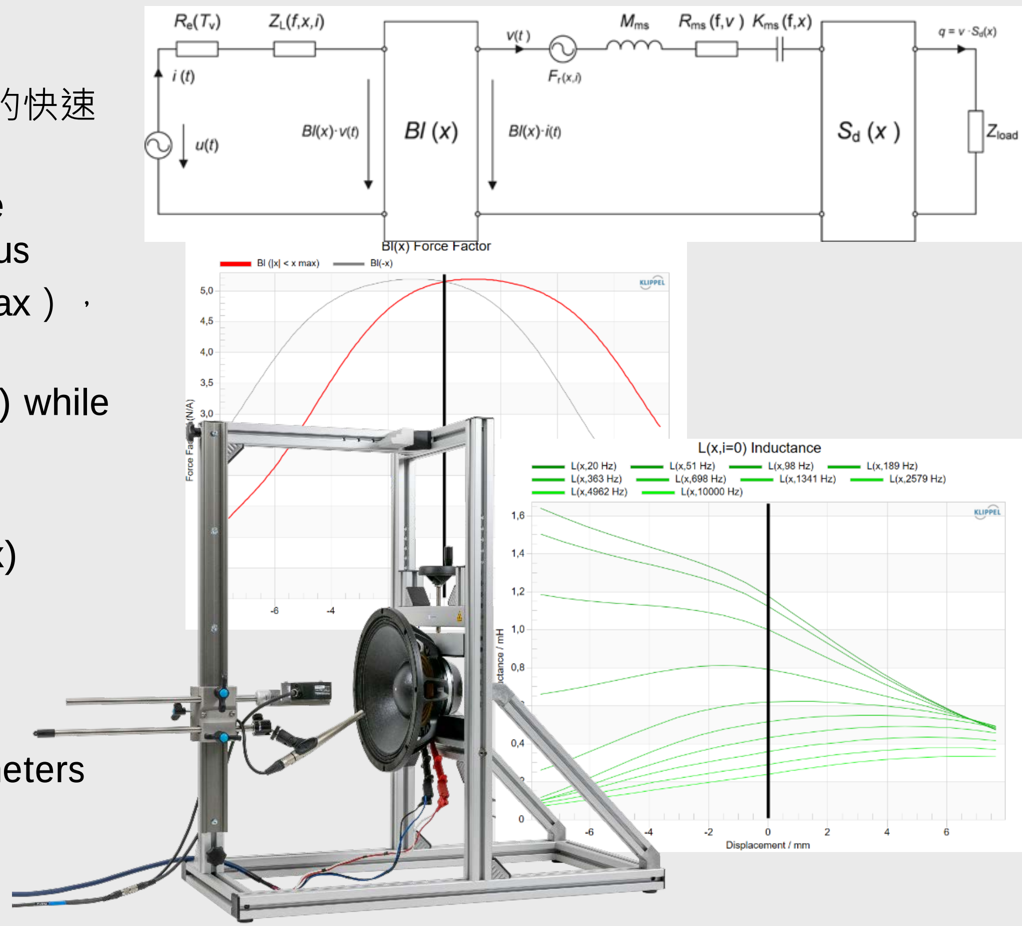
Considering higher-order loads (e.g. vented-box)

- 熱參數識別

Identification of thermal parameters

- 線性和非線性參數的解釋

Interpretation of the linear and nonlinear parameters



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總結 Summary

非線性測量參數
Measurement of Nonlinear Parameters

- 完整的動態量測技術更適合揚聲器
  Full dynamic measurement technique is most suitable for loudspeakers
- 現代的識別技術可以針對大小訊號進行即時的量測
  Modern identification techniques can measure small and large signal parameters on-line (in enclosure, music)
- 利用揚聲器作為感測器是可以進行快速量測與長時間監控
  Very fast measurements and long-term monitoring is possible using loudspeaker as sensor
- 不受環境噪音的影響
  Immunity against ambient noise
- 對於大訊號參數的解釋遠比解釋失真來得簡單
  Interpretation of large signal parameters is simpler than the the interpretation of distortion

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Part 6: Regular Nonlinear Distortion

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電聲產學技術發展與驗證聯盟

KLIPPEL

soma 尚馬電聲科技有限公司 acoustic co., ltd.

非線性失真（單音）（TRF、DIS）
Nonlinear Distortion (single tone) (TRF, DIS)
Experiment 8

只需最少的測試工作即可對以下症狀進行揚聲器診斷：

Loudspeaker Diagnostic on following symptoms with minimum test effort:

- 基本非線性壓縮（最少溫升)

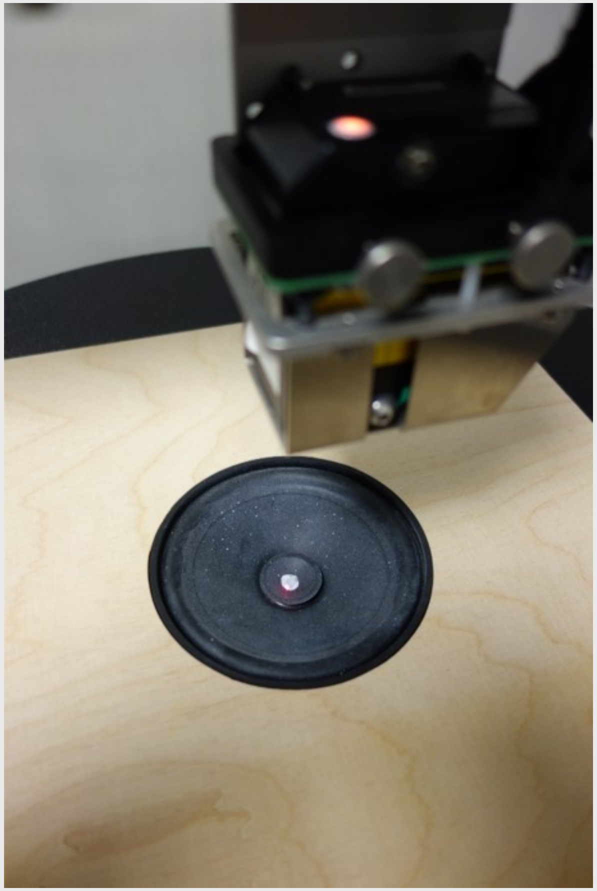
Nonlinear Compression of the Fundamental (minimal heating)

- 使用三角測量雷射測量直流位移

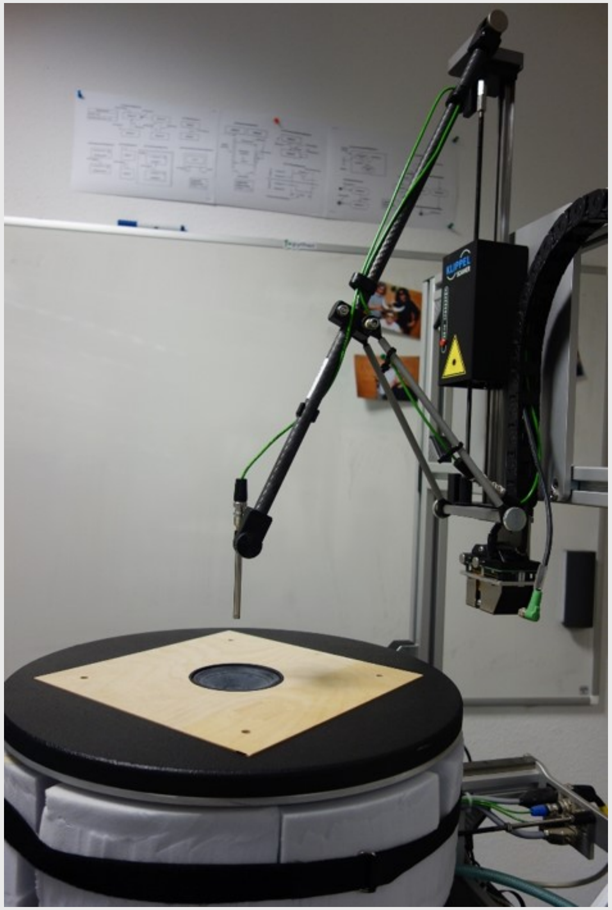
DC displacement measured with Triangulation Laser

- 諧波失真（線性調頻脈衝刺激）

Harmonic Distortion (Chirp stimulus)



互調失真測量 (MTON)
Intermodulation Distortion Measurement (MTON)
Experiment 9



只需最少的測試工作即可對以下症狀進行揚聲器診斷：

Loudspeaker Diagnostic on following symptoms with minimum test effort:

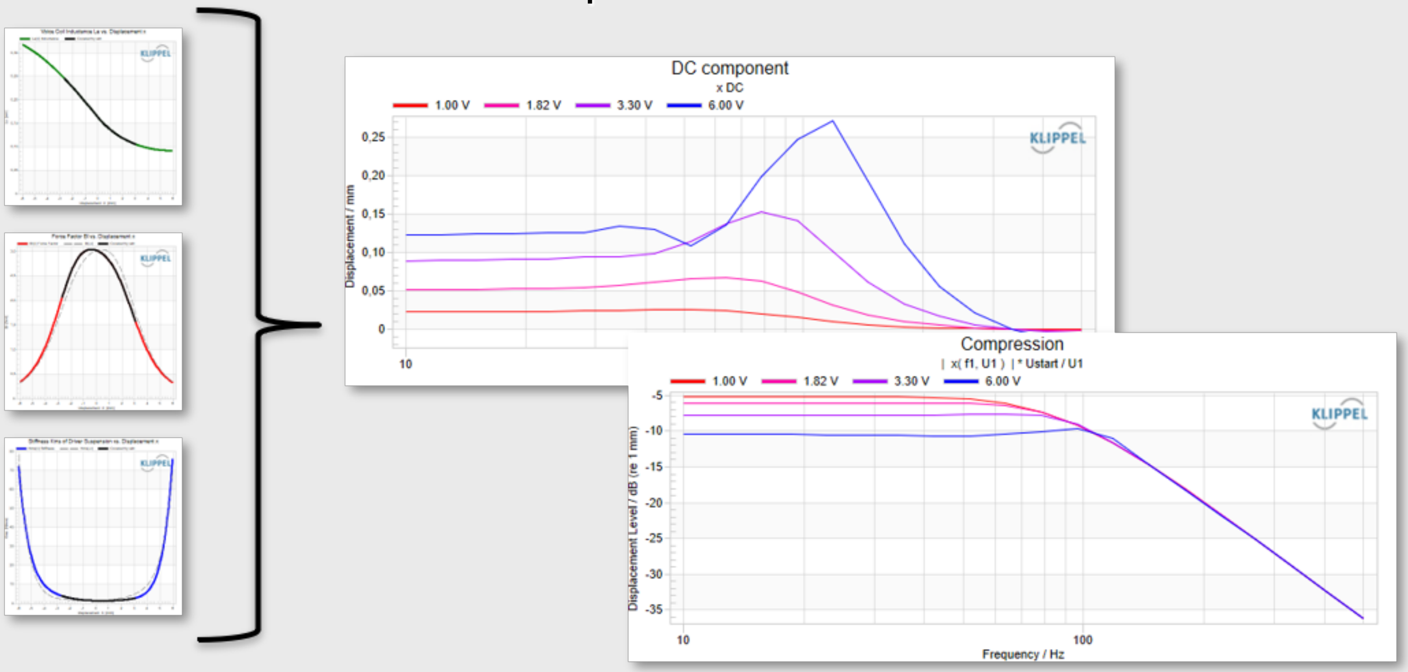
- 雙音激發互調失真 (DIS)

Intermodulation Distortion with Two-tone Stimulus (DIS)

- 由代表典型音訊訊號的稀疏多音刺激產生的失真頻譜 (MTON)

Distortion Spectrum generated by sparse multi-tone stimulus representing typical audio signals (MTON)

非線性症狀模擬 (SIM)
Simulation of Nonlinear Symptoms (SIM)
Experiment 10



- 預測非線性壓縮和直流位移 Predicting Nonlinear compression and DC displacement
- 預測諧波失真 Predicting Harmonic Distortion
- 預測互調失真（聲音掃描） Predicting Intermodulation Distortion (voice sweep)
- 量測與仿真的比較 Comparing Measurement with Simulation
- 顯示 Bl(x) 和 Kms(x) 的貢獻 Showing the contribution from Bl(x) and K_{ms}(x)

本節概要

Questions addressed in this section

- 如何執行有意義的大信號測試?
  How to perform meaningful measurements in the large signal domain ?
- 如何說明設計的結果及改善設計?
  How to interpret the results and to improve the design ?
- 如何取得系統設計完整的所需資料?
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  How to get maximal bass out of a small enclosure ?
- 如何得到有意義的失真測量 ?
  How to do meaningful distortion measurements ?

Summary

如何妥善處理非線性 How to cope with nonlinearities

- 測量諧波和互調 Measure harmonics and intermodulation

  → 使用多音激發Use multi-tone stimulus

- 在近場測量非線性失真 Measure nonlinear distortion in the near field

  → 確保足夠的信噪比 ensure sufficient SNR

- 將失真轉換成揚聲器的輸入Transform distortion to the loudspeaker input

  → 等效輸入失真的概念 concept of equivalent input distortion

- 注意非線性之間的相互作用Be aware of interactions between nonlinearities

  → 不需要補償 no compensation of Kms(x), Bl(x), L(x)

- 檢測直流分量Check for dc-displacement

  → 不穩定性 instability

- 使用數值類比軟體 Use numerical simulation tool

  → 看THD, X_{max}, SPL_{max}, IMD, P_{max} ,T的影響 see impact on THD, X_{max}, SPL_{max}, IMD, P_{max} ,T

音頻系統的聲音品質
Sound Quality of Audio Systems

Part 7: 隨時間變化的參數 (功率控制,熱傳,老化,氣候影響)
Part 7: Time-varying Properties (Power Handling, Heat Transfer, Aging, Climate Impact)

2024

Klippel GmbH

尚馬電聲科技有限公司 acoustic co., ltd.

DEMO

如何解釋 KLIPPEL 模組的結果 How to interpret the results of the KLIPPEL module

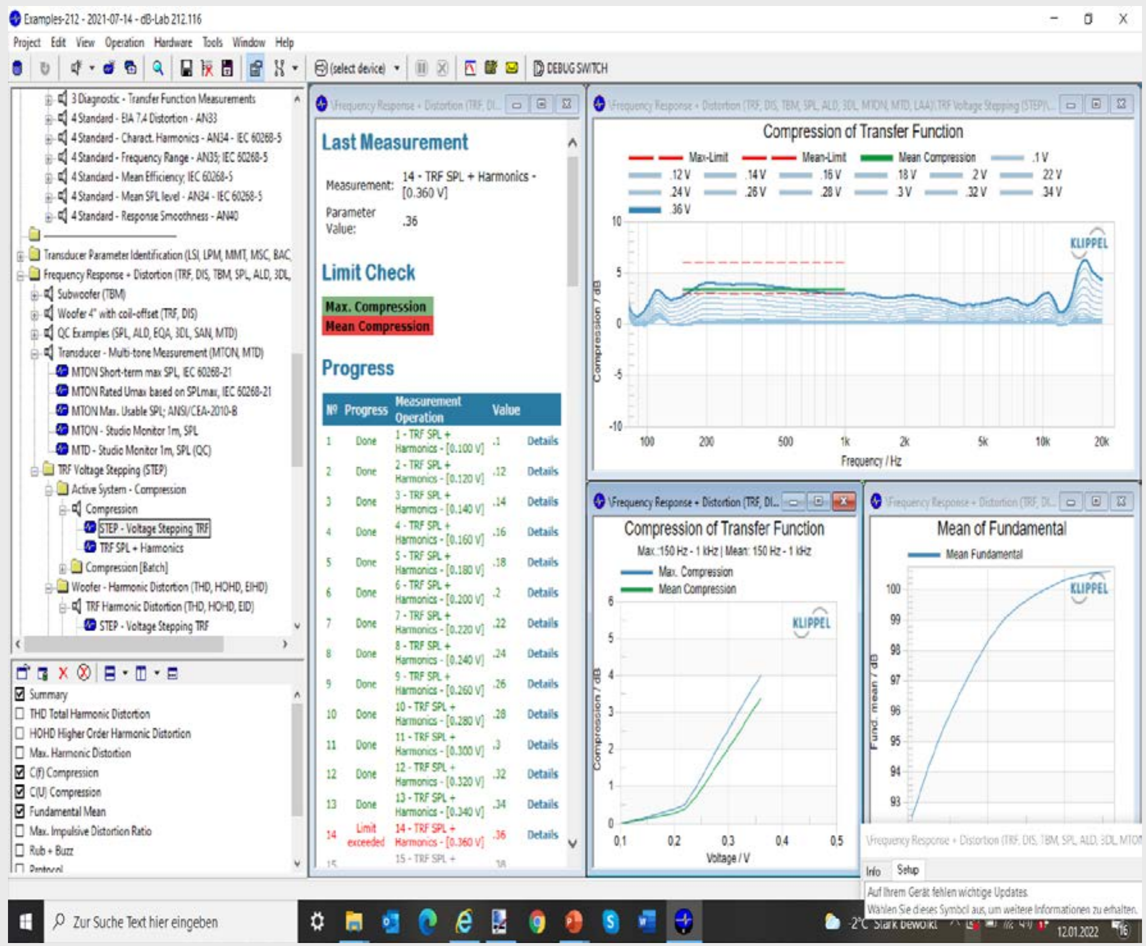
幅度壓縮（TRF 電壓步進）
Amplitude Compression (TRF Voltage Stepping)

1. 從 www.KLIPPEL.de 下載免費的 KLIPPEL 軟體 dB-Lab
Download free KLIPPEL software **dB-Lab** from www.KLIPPEL.de

1. 開啟資料庫 example-212.kdbx
Open database example-212.kdbx

1. 選擇資料夾頻率響應 + 失真/TRF 電壓步進 (STEP)/主動系統 – 壓縮和物件壓縮
Select folder Frequency Response + Distortion/TRF Voltage Stepping (STEP)/Active System – Compression and object Compression

1. 點選操作STEP - 電壓步進TRF
Click on operation STEP - Voltage Stepping TRF



總結Summary

幅度壓縮 Amplitude Compression

- 是評定最大聲輸出的重要特性 Is an important characteristic for rating the maximum acoustical output
- 取決於特定的刺激 Depends on the particular stimulus
- 是換能器的自然效應（接近過載）Is a natural effect of transducers (close to overload)
- 有意在帶有限制器、保護系統和其他 DSP 軟件的有源系統中生成（為 THD 交易幅度壓縮！！）Is intentionally generated in active systems with limiters, protection systems and other DSP software (Trading amplitude compression for THD !!)
- 可在換能器的近場測量，無需使用房間校正曲線 Can be measured in the near field of the transducer without using a room correction curve

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Part 8: Rub & Buzz以及其他不規則揚聲器缺陷
Part 8: Rub & Buzz and Other Irregular Loudspeaker Defects

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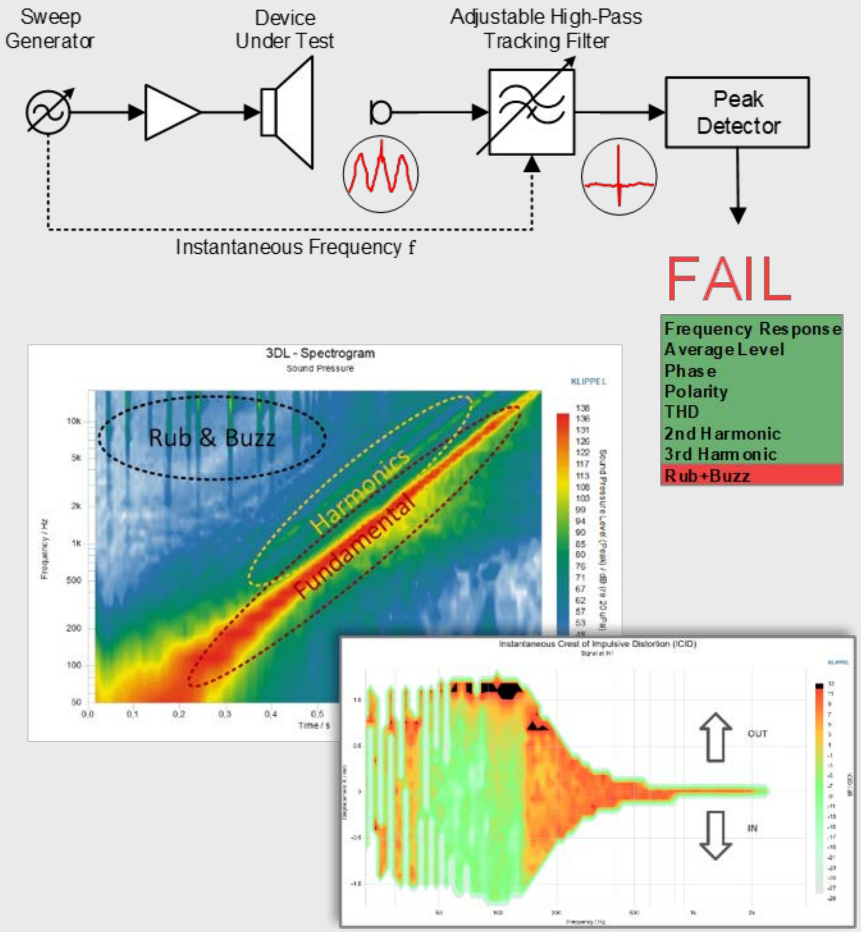
常見問題

Our Questions:

- 為什麼總諧波失真的測量對異音以及其他揚聲器缺陷不敏感?
  Why does total harmonic distortion measurement (THD) is not sensitive for rub and buzz and other loudspeaker defects ?
- 哪種測量是有意義的?
  Which kind of measurements are meaningful ?
- 要如何對揚聲器的缺陷有最大靈敏度?
  How to get maximal sensitivity for loudspeaker defects ?
- 如何辨別音圈碰撞,摩擦,鬆散微粒和其它缺陷?
  How to distinguish voice coil rubbing, from buzzing, loose particles and other defects ?
- 如何做到可靠且可重複的測量?
  How to do reliable and reproducible measurements ?
- 如何縮短測試時間?
  How to shorten the measurement time ?
- 如何應對環境雜訊?
  How to cope with ambient noise ?
- 我們需要測量箱體和其他聲學檔板嗎?
  Do we need a measurement box and other acoustical shielding ?

脈衝失真（Rub&Buzz）（QC、TRF STEP）
Impulsive Distortion (Rub&Buzz) (QC, TRF STEP)
Experiment 11



- 可靠地檢測缺陷和不規則揚聲器行為

Reliable detection of defects and irregular loudspeaker behavior

- 搜尋最大電壓（最大聲壓級），無異音

Searching for max voltage (max SPL) without rub & buzz

- 用於診斷不規則噪音和失真的時頻分析

Time-frequency analysis for diagnostics of irregular noise and distortion

- 在嘈雜的生產環境中進行快速而靈敏的揚聲器測試

Fast, but sensitive speaker testing in noisy production environment

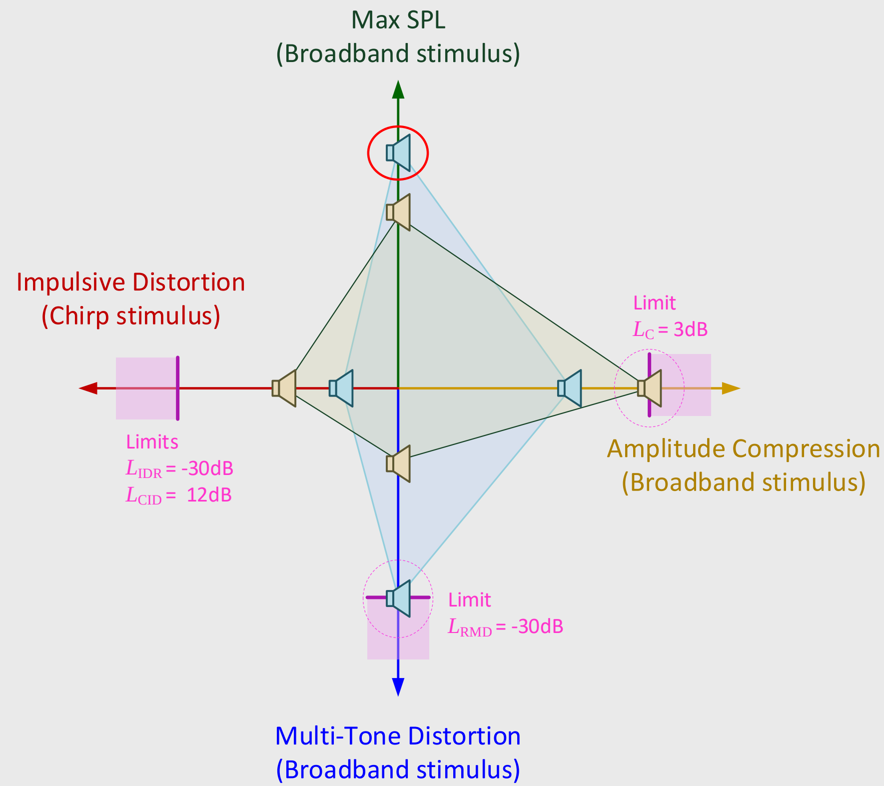
最大 SPL 評估 (IEC 60268-21) (MTON)
Maximum SPL Assessment (IEC 60268-21) (MTON)
Experiment 12

- 使用步進多音進行幅度壓縮和失真測試 Amplitude compression and distortion testing with stepped multi-tone
- 最大輸入電壓下的脈衝失真測試 Impulsive Distortion testing at maximal input voltage

a

- 定義 100 小時耐久性測試的候選電壓 utestDefining candidate voltage u_{test} for 100 h endurance test
- 執行並評估長期測試 Perform, and evaluate long-term test

b



總結
Summary

揚聲器非常規失真 Irregular Loudspeaker Distortions

- 由揚聲器的缺陷產生
  are generated by loudspeaker defects
- 被認可的模型和黃金樣品中不存在非常規失真
  not found in approved prototypes, golden reference unit
- 難以預測或建模
  are difficult to predict or model
- 由製造過程、超載工作、材料老化和環境變化導致
  are caused by manufacturing, overload, ageing and ambient conditions
- 隨時間變化且與工作環境（如鬆散粒子）有關
  are time variant and depend on the operation condition (e.g. loose particle)
- 與成本、大小和重量沒有直接的聯繫
  not directly related to cost, size, weight
- 如果發出聲音，客戶將無法接受
  inacceptable by customer if become audible

結論
Conclusions

- 缺陷經過運輸，在最終使用場合會更嚴重

  Defects may become worse after shipping and in final application
- 有缺陷的揚聲器不應該出貨給用戶

  Defective loudspeakers should not be shipped to the customer
- 需要靈敏測量系統，它會比使用者的耳朵更加靈敏 Sensitive Measurement techniques are required more sensitive than the ear of the customer
- 可靠的測量應考慮環境雜訊的影響

  Reliable measurements require automatic detection of invalid tests corrupted by ambient noise
- 揚聲器診斷表明了缺陷最根本的原因

  Loudspeaker diagnostic shows the root cause of the defect
- 生產中需要控制工藝，動作迅速以保證高產量

  Process control and fast action is required to ensure high yield rate in production

音頻系統的聲音品質

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Part 9: 可聽的信號失真

Part 9: Audibility of Signal Distortion

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電聲產學技術發展與驗證聯盟

尚馬電聲科技有限公司 acoustic co., ltd.

總結Summary

- 感知的音頻質量不僅取決於 DUT，還取決於測試條件（刺激、房間、氛圍、測試策略） The perceived audio quality depends not only on the DUT but also on the test condition (stimulus, room, ambience, test strategy)
- 失真分量可以作為建模和測量的殘餘物分離Distortion components can be separated as a residuum of modeling and measurement
- 可聽化技術可以生成具有修正失真率的聲音輸出Auralization techniques can generates a sound output with a modified distortion ratio
- 信號失真的可聽化結合感知和物理評估Auralization of signal distortion combines perceptual and physical assessment
- 可聽化簡化聽力測試並在更短的時間內提供更多信息Auralization simplifies listening tests and provide more information in a shorter time
- 可聽化加速產品開發Auralization speeds up product development

音頻系統的聲音品質
Sound Quality of Audio Systems

Part 10:非線性自適應控制
Adaptive Nonlinear Control
Part 10: Adaptive Nonlinear Control

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非線性自適應控制

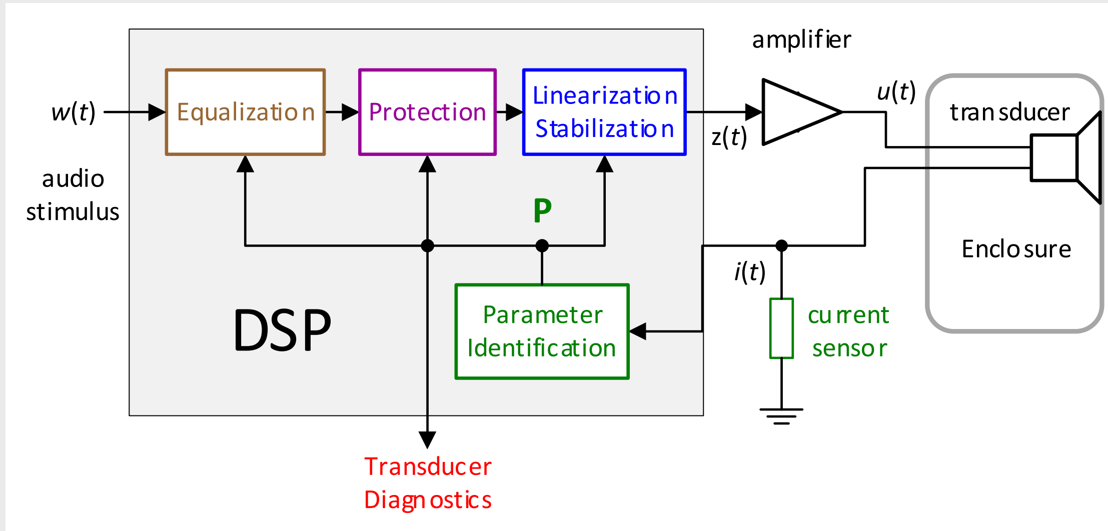
Part 10: Nonlinear Adaptive Control

Loudspeakers and Headphones

- 透過DSP 數位信號處理軟體的新功能補充揚聲器硬體上的限制及不足
  DSP Software complements the loudspeaker hardware with new functionality
- 自適應非線性控制 (KCS) 能在**更小**的揚聲器中以**更好**的音質產生**更多**的輸出
  Adaptive nonlinear control (KCS) generates more output at the better sound quality from smaller speakers
- 綠色揚聲器設計使用揚聲器非線性和模態共振來提高效率和電壓靈敏度
  Green Speaker Design uses loudspeaker nonlinearities and modal resonances for improving efficiency and voltage sensitivity
- 非線性失真消除提供線性整體響應
  Nonlinear distortion cancellation provides a linear overall response
- 自動均衡簡化了揚聲器的開發
  Automatic equalization simplifies the loudspeaker development
- 有源音圈穩定對於提供最大位移 Xmax 和可靠的過載保護非常重要
  Active voice coil stabilization is important for providing maximum displacement X_{max} and reliable protection against overload
- 基於電流感測的在線診斷提高了揚聲器在產品生命週期內的可靠性
  On-line diagnostics based on current sensing increases the reliability of the loudspeaker over the product life
- 有源換能器模塊（DSP+ 放大器 + 換能器）提供更高的電壓靈敏度，同時減少電纜問題和成本（使用簡化輸出濾波器的 D 類放大器）
  Active transducer modules (DSP+ Amp + transducer) give more voltage sensitivity while reducing cable problems and cost (class D amplifiers using simplified output filter)

自適應非線性控制
Adaptive Nonlinear Control

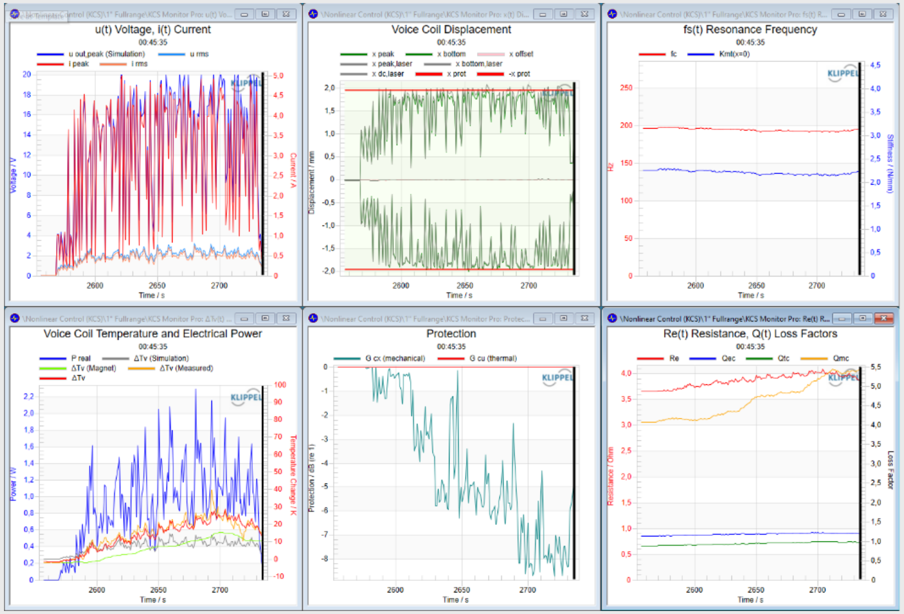
e.g., KLIPPEL Controlled Sound (KCS)



- 在整個工作範圍內對揚聲器進行精確建模
  Accurate modeling of the loudspeaker over the full working range
- 通過電流監測自適應識別換能器參數
  Adaptive identification of the transducer parameters P by current monitoring
- 鏡像濾波器消除直流位移、諧波和其他非線性揚聲器失真
  Mirror Filter cancels DC displacement, harmonics and other nonlinear speaker distortion
- 主動穩定音圈靜止位置
  Active stabilization of the voice coil rest position
- 可靠的熱過載和機械過載保護
  Reliable protection against thermal and mechanical overload
- 自動均衡到目標對準（fs 的虛擬偏移、QTS 等）
  Automatic equalization to a target alignment (virtual shift of f_s, Q_{TS}, ...)
- 系統在線診斷 On-line diagnostic of the system

在線監控
Online Monitoring and Control (KCS)
Experiment 12

- 保護 Protection
  - 熱力和機械
    Thermal and mechanical
  - 揚聲器老化和缺陷的處理
    Handling of loudspeaker aging + defects
- 長期監測 Long-term monitoring
  - 音圈溫度和傳熱
    Voice coil temperature and heat transfer
  - 由於氣候、老化而導致的時變特性（音圈位置、懸架）
    Time-variant properties (voice coil position, suspension) ➔ climate, aging
- 線性化 Linearization
- 自適應均衡 Adaptive equalization



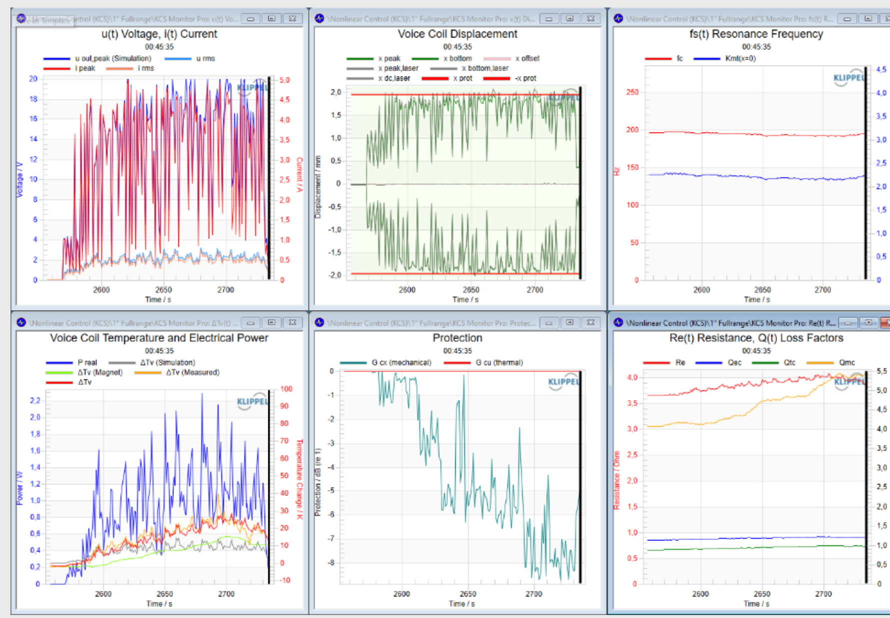
線上監控（KCS）
Online Monitoring and Control (KCS)

Experiment 13

- 保護 Protection
    - 熱學和機械學

  Thermal and mechanical
    - 揚聲器老化和缺陷的處理

  Handling of loudspeaker aging and defects
- 長期監測 Long-term monitoring
    - 音圈溫度與傳熱 Voice coil temperature and heat transfer
    - 由於氣候、老化而導致的時變特性（音圈位置、懸吊） Time-variant properties (voice coil position, suspension) due to climate, aging
- 線性化 Linearization
- 自適應均衡 Adaptive equalization



透過音樂信號測量失真
Distortion Measurement with Music (NRL, TFA)
Experiment 14

- Nonlinear residuum of adaptive linear modeling
- Time-variant linear transfer function (heating, aging)
- Time-Frequency Analysis of the residuum
- Auralization of the residuum to asses audibiltiy and impact on audio quality